

EOS Terra

Mission Status
at
Earth Science
Constellation
MOWG Meeting
@ GSFC

June 2nd, 2015



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Topics

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- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities**
- **Inclination Adjust Maneuvers**
- **Conjunction History**
- **Propellant Usage & Lifetime Estimate**
- **End-Of-Mission Plan**
- **Summary**
- **Additional Slides:**
 - Orbit Maintenance Maneuvers
 - Ground Track Error & Mean Local Time History
 - MLT History
 - EPS Performance and Improvements

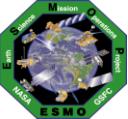


EOS Terra Mission Summary



- Mar 2013: Mission Extension Senior Review
Proposal Panel Report
 - Mission extension through FY17
 - Senior Review submissions – delivered in March 2015
- 2014-15 Inclination Adjust Maneuvers
 - Fall 2014 Inclination Maneuvers
 - IAM #39 - October 29th
 - Spring 2015 Inclination Maneuvers
 - IAM #40 - February 19th
 - IAM #41 - February 25th
 - Fall 2015 Inclination Maneuver
 - October 29th
- 12/18/14: Terra 15-Year Anniversary
 - 5-Year Design Life, 6 year goal
 - Reliability Estimates thru 2020+
 - Consumables through 2017+
- 02/20/16: EOS Flight Operations Annual Review #8





Terra Spacecraft Status



All subsystems on Primary Hardware except as noted

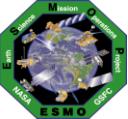
- **Command & Data Handling (CDH)** – Nominal
 - Solid State Recorder (SSR) – only holds 1 orbit of data
 - **10** of 58 SSR Printed Wire Assembly tripped off resulting in reduced recording capacity
- **Communications (COMM)** – Nominal
 - DAS Modulator Failure on 05/29/2008 (Operating on Redundant)
 - Use K-Band primarily, X-Band as needed for Science Playback
- **Electrical Power System (EPS)**
 - Battery Cell and Heater Controller Anomaly (10/13/2009)
 - 1 of 24 Solar Panel Failed (9/24/2000)
- **Flight Software (FSW)** – Nominal
- **Guidance, Navigation & Control (GN&C)** – Nominal
 - Minor loss of sensitivity in SSSTs – updated tracker biases to compensate
- **Propulsion (PROP)** – Nominal
- **Thermal Control System (TCS)** – Nominal
- **Instruments (INST)** – Nominal
 - Only ASTER SWIR failed, all other instruments are taking science



Spacecraft Component Status



Subsystem	Component	Design	Current	Capability	Comments
EPS	Solar Array	24 Shunts	23 Shunts	96%	Degradation is minimal. Fully capable of supporting mission thru 2020 unless future failures occur
	Batteries	108 Cells	107 Cells	99%	BBAT cell #50 failed on 10/15/09.
	Batteries	36 Heater Controls	28 Heater Controls	77%	BBAT heater control failed on 4 of 9 heater groups on primary, redundant, and survival. Battery cell charging/discharging and the remaining heater groups are preventing cells from freezing. PBAT heater control performance is nominal.
TCS	MOPITTCPHTS	2	2	Full	Performance is nominal
	SWIR CPHTS	2	2	Full	Performance is nominal
	TIR CPHTS	2	2	Full	Random temperature fluctuations. Performance within requirements.
SCC	SCC	2	2	Full	Performance is nominal
COMM	HGA	2	2	Full	MDA BITE failures occur 2-3/week due to SEU. Recoverable
	X-Band	2	1	75%	DAS Modulator 1 failed (50%). Solid State Power Amplifier redundancy still available (100%).
	CTIU	2	2	Full	Performance is nominal
	OMNI	2	2	Full	Performance is nominal
CDH	MO	2	2	Full	Drift rate changes have occurred since 10/3/10. Performance is within requirements.
	SFE	2	2	Full	SFE SEU occur 1-2/year. Recoverable
	SSR	59 PWA	49 PWA	83.1%	Recycle of Data Memory Unit likely to recover all Printed Wire Assemblies
GNC	IRU	3	3	Full	Performance is nominal. 2 for 3 redundancy
	TAM	2	2	Full	Performance is nominal
	SSST	2	2	Full	Minor loss of sensitivity in SSSTs – tracker biases updated
	CSS	2	2	Full	Performance is nominal
	ESA	2	2	Full	Performance is nominal
	FSS	1	1	Full	Performance is nominal. Not currently used
	RWA	4	4	Full	Performance is nominal. 3 for 4 redundancy
	MTR	3	3	Full	Performance is nominal
Prop	REAs	16	16	Full	Performance is nominal
Instruments	ASTER - SWIR	2	2	0%	Cooler is unable to maintain detector temperature. Science Data is unusable (Fully Saturated) and is no longer being recorded. Still collecting and monitoring Engineering data.
	ASTER - TIR	2	2	Full	Performance is nominal
	ASTER - VNIR	2	2	Full	Performance is nominal
	CERES - Aft	1	1	Full	Performance is nominal
	CERES - Fore	1	1	Full	Performance is nominal
	MISR	2	2	Full	Performance is nominal
	MODIS	2	1	50%	Power Supply #2 failed, Formatter A degraded, cross-strapped. All Science is nominal.
	MOPITT	2	1	50%	Displacer B and Chopper Motor failed. Loss of redundancy only. All Science is nominal.



Recent Activities



• Propulsive Maneuvers

- Inclination Adjust Maneuver (IAM) #39 on 10/29/14
- Drag Make Up Maneuver (DMU) #86 on 11/13/14
- Drag Make Up Maneuver (DMU) #87 on 12/12/14
- Drag Make Up Maneuver (DMU) #88 on 12/31/14
 - Debris Avoidance Maneuver (DAM) #8
- Drag Make Up Maneuver (DMU) #89 on 02/04/15
- Inclination Adjust Maneuver (IAM) #40 on 02/19/15
- Inclination Adjust Maneuver (IAM) #41 on 02/25/15
- Drag Make Up Maneuver (DMU) #90 on 03/04/15
- Drag Make Up Maneuver (DMU) #91 targeted for 04/22/15

• Calibration Maneuvers

- MODIS Roll #144 executed on 10/12/14
- MODIS Roll #145 executed on 11/11/14
- MODIS Roll #146 executed on 12/11/14
- MODIS Roll #147 executed on 01/10/15
- MODIS Roll #148 executed on 02/09/15
- MODIS Roll #149 executed on 03/10/15
- MODIS Roll #150 executed on 04/09/15

- **10/14/14: Terra Failed PWA Anomaly (PWA-57) affecting MODIS and TRASH**
- **10/15/14 – 10/17/14: Constellation MOWG @ LaRC Hampton, VA**
- **10/24/14 – 10/25/14: NAV Table uplink Issues due to FDF TDRS Solar Eclipse prediction issues**
- **10/25/14: MODIS Data Corruption (SFE) Anomaly**
- **11/19/14: DMU RTCSs (FSSE CCR-0284) Successfully Uplinked**
- **12/18/15: Terra 15th Launch Anniversary (12/18/1999)**
- **01/16/15: Full Team Terra SCC2 Recovery Simulation**
- **01/21/15: EOS 2015 Annual Review**
- **02/05/15: Terra Star Tracker Bias Patch Uplink**
- **02/11/15 – 02/12/15: ASTER Interface Meeting**
- **03/23/15 – 04/03/15: MOPITT Hot Cal & Decontamination**
- **04/10/15 & 04/14/2015: SFE Off Anomaly (TMON 16 Successfully Recovered)**



Future Plans

Upcoming Activities

MOPITT Hot Calibration & Decontamination **March 23, 2015 – April 4, 2015**

MODIS SRCA Spectral Calibration CAM **April 1, 2015 @ 3 PM**

MODIS SRCA Spectral Calibration **April 6, 2015 – April 8, 2015**

Start of Online 19.06 OPS Delivery **April 23, 2015 – May 01, 2015**

Quick Debris Avoidance Maneuver TMON/RTCS **Late April 2015**

Online 19.06 OPS FOT Checkout **May 01, 2015 – May 12, 2015**

Terra FSSE CCB **May 07, 2015 @ 2 PM**

Update Drag Scale Factor **2Q2015**

Ground Based Automation Implementation **2Q2015**

Activity log PB and SA adjusts, improve SSR automation via FSW **3Q2015**

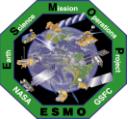
Leap Second # 36 **June 30, 2015**

HGA Model/Keyhole Unwind; MMS Dev - HGA Gimbal motor sun exposure model **3Q2015**



Inclination Adjust Maneuvers

- Inclination Adjust Maneuvers used to maintain nominal spacecraft mean local time (descending node) of 10:30 AM
 - 02/19/2015 Inclination Adjust Maneuver #40 (320 sec burn)
 - 02/25/2015 Inclination Adjust Maneuver #41 (320 sec burn)
 - Oct/Nov 2015 Inclination Adjust Maneuver #42 (320 sec burn)
- Current predictions indicate need to perform 3 maneuvers per year
 - (2 in Spring, 1 in Fall) to maintain 10:30am +/- 1 minute goal



Terra High Interest Events



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014 (T1-T4)	1	2	3	1	1	2	1	1	2	1	4	5	24
Tier 3	0	2	1	1	0	1	0	0	1	0	1	2	9
Tier 4	0	2	1	0	0	0	1	0	0	0	1	1	6
2015 (T1-T4)	5	2	4										11
Tier 3	2	0	0										2
Tier 4	1	0	0										1

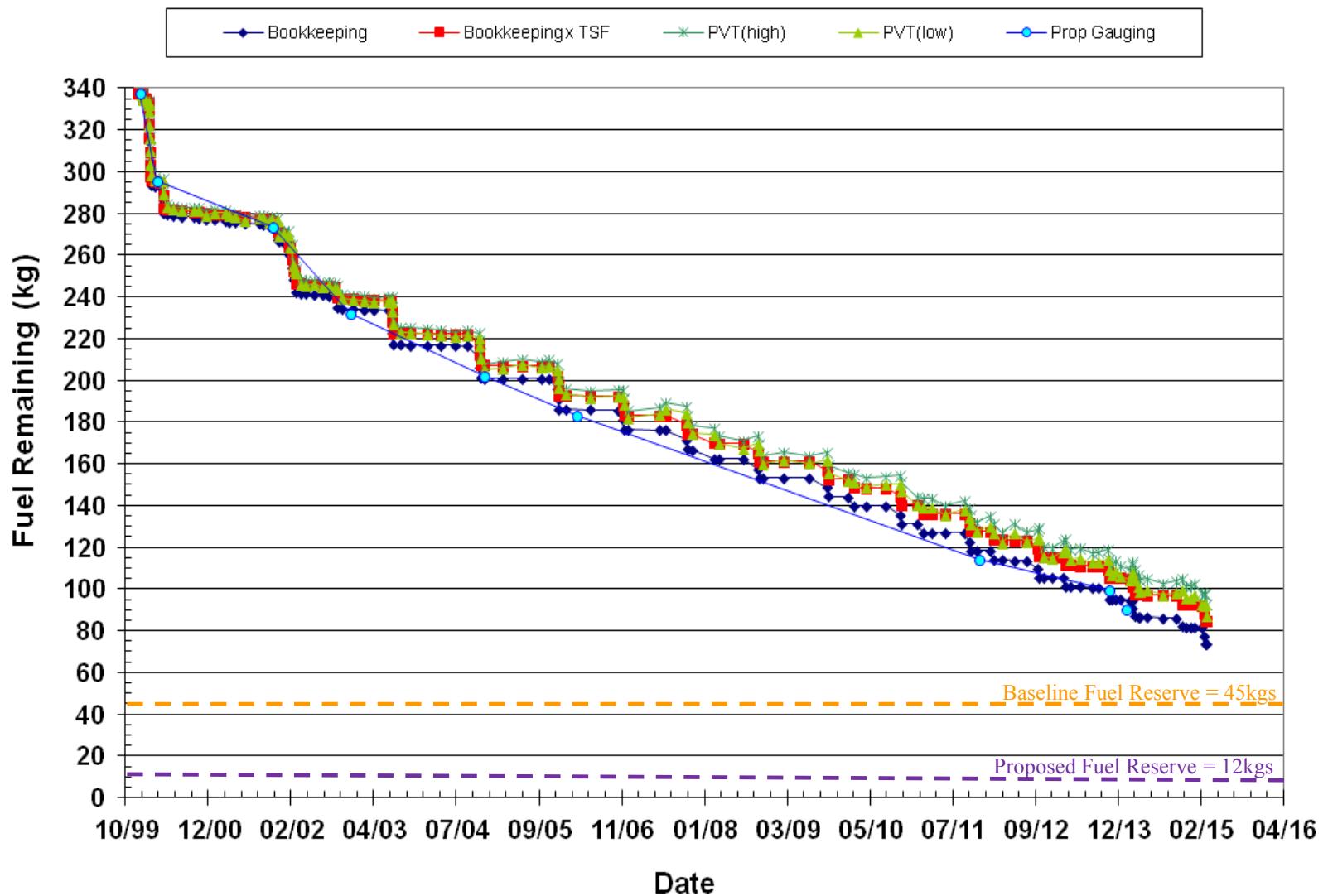
CARA Defines the 4 Tiers as: T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver

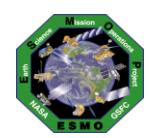
- **2005:** 4 HIEs – 1 Debris Avoidance Related Maneuver (DARM) performed on 10/21/2005: Terra vs. 14222 CA on 10/23
- **2006:** 1 HIE – 1 maneuver waived off due to CA. Maneuver originally planned for 01/12/2006: Terra vs. 1716 CA on 1/12@ 17:46z
- **2007:** 4 HIEs – 1 DARM performed on 06/22/2007: Terra vs. 31410 CA on 6/23
- **2008:** 2 HIEs – 1 DARM planned and waived off: Terra vs. 82832 CA on 10/28/2008 @ 06:17z
- **2009:** 2 HIEs – No DARMs planned or performed
- **2010:** 5 HIEs – 1 DARM performed on 01/22/2010: Terra vs. 34700 CA on 1/23 @ 20:46z
- **2011:** 20 HIEs – 2 DARM planned and waived off: (1) Terra vs. 26181 CA on 3/28/2011 @ 12:14z (2) Terra vs. 30440 Repeating CA 05/07-09/2011
- **2012:** 19 HIEs – 1 maneuver waived off due to CA. Maneuver originally planned for 05/31/2012: Terra vs. 37789 CA on 6/1 @ 22:49z
- **2013:** 17 HIEs – 7 that required significant action
- **2014:** 24 HIEs – 6 that required DAM execution or nominal maneuver waive-off and replan
- **2015 thru present: 11 High Interest Events (HIEs) – 3 that required DAM execution or nominal maneuver waive-off and replanning**
 - 12/31/2014: CAs vs. 35925 TCA Thu 01/01 at 08:02:55 GMT – RED HIE, repeating CAs (10) DAM #9 planned and executed (T4)
 - 01/02/2015: CAs vs. 87161 TCA Sun 01/04 at 18:26:50 GMT – RED HIE, repeating CAs (8+), DAMs planned, not actionable (T3)
 - 01/11/2015: CAs vs. 80767 TCAs 01/14 and 01/15 – Repeating CAs (16), DAMs planned, no viable maneuver, suspended planning (T3)



Lifetime Fuel Estimate

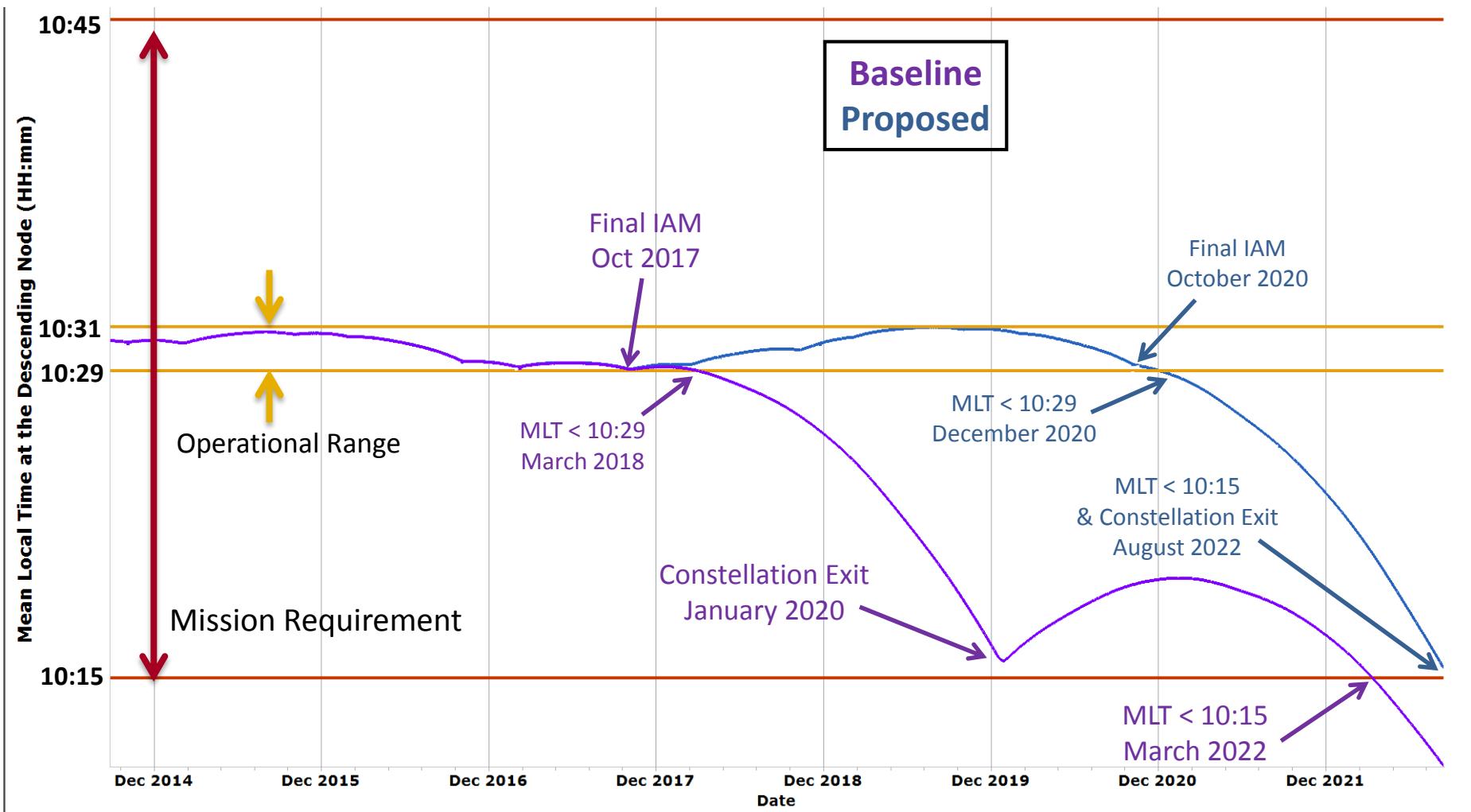
Terra Fuel Usage Comparison





Baseline vs. Proposed Constellation Exit Plan

Mean Local Time Prediction





Terra End-of-Mission Plan



Document Status

- **End-of-Mission Plan Document has been revised and in signature cycle**

Content

- Terra will continue normal operations through **October 2020**
- Once all non-reserved fuel has been used, MLT will be drifted to 10:15 AM
- **August 2022**, Terra will use remaining fuel to exit constellation
- Plan is consistent with the **revised Afternoon Constellation (A-Train) Operations Coordination Plan**
- Pending waiver approval

Earth Science Mission Operations Project

428-PLAN-002

EOS-Terra End of Mission Plan (EOMP)

Revision B

March 2013

Expires: March 2018



GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Check Configuration Management EOS Tool at <http://ops1-cm.ems.eosdis.nasa.gov/cm2/> to verify that this is the correct version prior to use.



Summary

- **Terra remains very healthy 15+ years into the mission**
 - Electrical Power Subsystem performance has been stabilized following 2009 anomaly
 - Fuel Remaining to continue operations to 2020 and beyond
- **Data Capture percentages continue at ~100%**
- **Collision Avoidance events are increasing in frequency**
- **FOT continues to monitor all trends/anomalies**
- **Mission Operations continues to come up with new ideas/process improvements to maximize mission life and efficiency**



Additional Slides

- Orbit / Inclination / MLT Maintenance
- WRS Ground Track Error
- EPS Performance and Improvements



Orbit/Inclination/MLT Maintenance

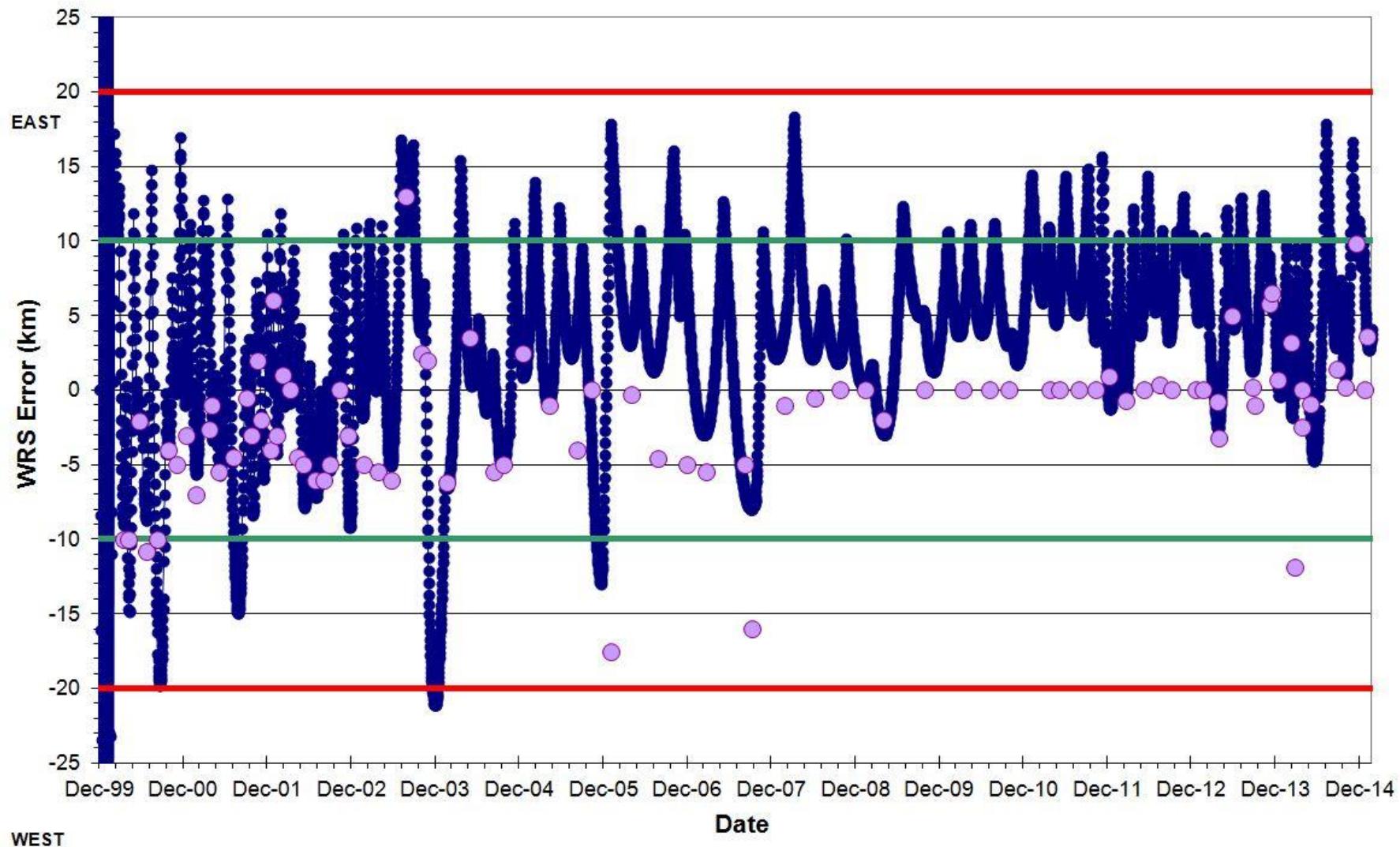
- **Requirement:** Mean Local Time (MLT) maintained between 10:15 and 10:45 measured at the Descending Node.
- **Goal:** Maintain Terra mean local time of the descending node (MLTDN) below 10:31.
- **Constraint:** OCO-2 has requested Terra maintain a MLT less than 10:31 for the duration of its lifetime to maintain a safe separation at the poles.
- **Requirement:** Maintain WRS-2 ground track error, 0 +/-20 km.
- **Requirement:** Maintain Frozen orbit with Argument of Perigee at 90 degrees +/-20 and Eccentricity of 0.0012 +/- 0.0004.
- **Constraint:** Maximum burn duration limited to 320 seconds by spacecraft manufacturer. Complete yaw slews and inclination maneuvers during spacecraft orbital night. Maneuver close to spring and fall equinox to maximize efficiency.



WRS Ground Track Error (GTE)



TERRA WRS Groundtrack Error at the Descending Node
(Maneuver planning targets included)





EPS Subsystem Performance



- **Bus Load: Nominal**
 - Average bus load: **2313 Watts**
 - Average housekeeping current: 11.93 A
 - Total instrument current: **7.143 A**
- **Battery Performance: Nominal with exception of anomalous BBAT condition**
 - BBAT cell # 50 failed following IAM #24 on October 13 (DOY 286) 2009
 - BBAT Voltage Temperature curve changed to better reflect a failed cell
 - BBAT heater control electronics (HCE) anomaly occurred following IAM #24 on October 13 (DOY 286) 2009
 - Performed soft reset, power cycle, switching to redundant side and re-enabling one of the nonfunctioning heater groups to recover HCE functionality without success
 - At least 4 of 9 BBAT heater groups are no longer being controlled
 - Heater control setpoints to changed for controllable heater groups to reduce the thermal gradient
 - PBAT Charge/Discharge Ratio was reduced from 105% to 104% on April 25, 2013 in an effort to extend PBAT life
 - **PBAT BPC Channel A Disabled January 14, 2014; increases BBAT cold temperatures due to increased discharge**
- **Battery Temperatures: Nominal with exception of anomalous BBAT data**
 - PBAT and half of BBAT Battery temperatures are regulated by flight software to $\approx -1^{\circ}\text{C}$ to -5°C
 - Almost half of BBAT cell temperatures are below normal (but stable) in the -5°C to -13°C range
- **Battery Voltages (BBAT)**
 - Minimum battery voltages at **66.14 Volts**
- **Solar Array**
 - Last offset adjustment performed on **December 18th 2014**
 - Average drift rate for the month, **-0.07 deg/day**
 - Present offset drift rate is decreasing
- **BBAT Cell with Lowest Temperature (excluding Cell #50)**
 - Cell # 21 : **-11.28°C**
 - Thermal Gradient(avg): **7.82°C**



Process Improvements

Battery/EPS Subsystem



- **Terra Hex Bay Battery (BBAT) experienced an anomaly in Oct 2009 – likely caused by Micro Meteoroid or Orbital Debris (MMOD)**
 - BBAT cell #50 was lost as well as several BBAT heater groups
 - Battery parameters were adjusted shortly after the anomaly to stabilize the battery performance
 - Battery performance has been stable since anomaly
- **ESMO team (MD/FOT/Spacecraft Manufacturer/FSSE) continue to come up with new ideas/methods to extend battery life and protect against future anomalies**

1. New SA Operations

- In August of 2013 the SA operations during maneuvers was adjusted to decrease DOD during maneuver orbits
 - Ranges from 5-20% DOD improvement, less overcharge & less temp fluctuation

2. Battery Power Conditioner (BPC) Channel Disable Activity

- In December of 2013 the team uplinked a new FSW patch to provide the ability to disable BPC channels (i.e. be able to shift the amount of discharge burden each battery carries)
- On January 14th, 2014 a BPC channel was commanded to be disabled
 - More total current is now drawn from BBAT (4/7ths or ~57% of overall current)
 - Generates more heat during discharge, therefore increase in cold cell temps
 - Have seen ~2° C increase in coldest cell temps & ~1.5° C decrease in thermal gradient
 - Allows for greater response time in a load shed or other anomalous condition, before batteries reach possible freezing temps

3. Capillary Pump Heat Transfer System (CPHTS) Heater reconfiguration to increase load

- SWIR Cryo-cooler and CPHTS Pump Heater test (Oct '13) - Increased ~40 W
- MOPITT CPHTS Pump Body Heater Test (Apr '14) – Increased ~75 W (Raised Cold Cells by ~0.65° C)

4. Hot Cell Set point Reductions to reduce thermal gradient

- Starting May 19th, 2014 the FOT reduced the heater set points of BBAT Heater groups 1, 2, 3 & 6 by 1° C
 - Reduced thermal gradient by ~ 0.5-0.75° C and reduced Cold Cells by ~0.1-0.25° C
- The thermal trends will continue to be reviewed to determine whether to reduce the set points of BBAT further

